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Aircraft Interior Panel Test Criteria Derived from Full-Scale Fire Tests

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16. Abstract

Full-scale cabin fire tests were conducted to determine potential increases in passenger survivability associated with different interior honeycomb panel constructions. The test fuselage was a C-133 with a simulated wide-body door opening exposed to an 8-foot by 10-foot fuel fire. In the first series, the interior near the door was lined with the honeycomb panels to determine whether earlier studies performed with small-scale enclosures were consistent with the full-scale counterpart. These earlier studies resulted in the selection of the Ohio State University (OSU) Rate of Heat Release Apparatus as the most appropriate type test to evaluate aircraft panels. The first series was followed by tests that included fire-blocked seats and carpeting as well as the panels to determine the type survivability increases that could be attained from low heat release materials. The scenario employed generally resulted with flashover within 2 minutes for panels considered typical in performance. A low heat release phenolic/fiberglass panel demonstrated a flashover delay until about 4 minutes into the test. An incombustible panel prevented flashover altogether. The performance of the various panels was evaluated to develop recommended flammability criteria for a modified OSU Rate of Heat Release Apparatus.

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EXECUTIVE SUMMARY

This report describes the derivation of improved small-scale fire test requirements for cabin interior panel materials from an analysis of full-scale postcrash cabin fire tests. The improved requirements are based on measurements made in a modified Ohio State University (OSU) heat release apparatus. The development of the OSU apparatus and the full-scale fire test conditions were recommendations of the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee. This work has resulted in the issuance of Notice of Proposed Rulemaking (NPRM) 85-10.

The full-scale fire scenario consisted of an intact fuselage with an open door adjacent to a large external fuel fire. Six types of interior honeycomb panels installed in a wide-body test article in a representative arrangement at sidewall, ceiling, stowage bin, and partition locations were evaluated. Two series of full-scale tests were conducted. In the first test series, each type of panel was evaluated without any other materials installed in the test article. The results of these tests demonstrated that the composition of the resin and cloth used in the panel facings had a significant effect on fire performance. This indicated that improvements in fire performance could be achieved by relatively minor modifications in panel design using state-of-the-art materials. Results from the first series of tests also indicated that the temperature increase inside the test article closely tracked the smoke and toxic gas concentration measurements. Since temperature rise is dependent, along with other factors, on the heat release rate characteristics of interior materials, this finding reinforced the selection of the OSU heat release apparatus by the SAFER committee for fire hazard assessment. In the second test series, the panels were evaluated in a more realistic cabin environment that included rows of aircraft seats protected with fire-blocking layers, as required by recent Federal Aviation Administration (FAA) rulemaking, and carpeting. The results from the second test series demonstrated that significant improvements in safety, or, more specifically, a delay in the onset of flashover, could be achieved through the utilization of aircraft panels with lower heat release rate characteristics. It was noteworthy that the fire safety benefits provided by improved panel design were in addition to the benefits provided by fire-blocking layer protection of aircraft seat cushions.

The full-scale cabin fire tests were analyzed in order to select for the OSU apparatus relevent test exposure conditions and measurements, as well as criteria for improved safety, to be utilized in conjunction with NPRM 85-10. It was determined that a radiant heat exposure of 3.5 watts per square centimeter and measurements of peak heat release rate and total heat release at 2 minutes correlated well with full-scale data. Using as a benchmark the performance of a phenolic/fiberglass panel, which is a state-of-the-art composite used in certain applications in cabin interiors, criteria was set at 65 kw/m^2 for peak heat release rate and 65 kw-min/m^2 for total heat release at 2 minutes. For the open door fire scenario studied, the phenolic/fiberglass panel added approximately 2 minutes to survivability when compared against other panels (e.g., phenolic/kevlar and epoxy/fiberglass). Thus, selection of interior panels based on the OSU apparatus test requirements set forth on the basis of full-scale tests could result in major safety gains during certain postcrash fire scenarios.

INTRODUCTION

PURPOSE.

The purpose of this work was to determine what safety improvements were achievable for aircraft interior cabin panels to enhance survivability in the event of a postcrash fire.

BACKGROUND.

Transport aircraft employ a wide variety of polymeric materials in their interiors. The collective performance of these materials under a given fire scenario can determine the time available for passenger escape during a postcrash fire. Prior to recent Federal Aviation Administration (FAA) rulemaking requiring seat blocking layers, the minimum fire safety requirements for the cabin interior were based on a 1972 rule that required carpets and seats as well as interior panels to be subjected to a Bunsen burner test. Because this test ensures that materials will resist ignition from relatively small ignition sources, the validity of the test is self-evident. In contrast, a postcrash fire can involve thousands of gallons of burning aviation kerosene from ruptured fuel tanks. Upgrading flammability requirements in the face of this type fire threat requires full-scale testing to determine the manner in which interior materials get involved.

In the mid 1970's the FAA issued an advance notice of proposed rulemaking (NPRM) on toxicity, an NPRM on smoke, and an additional NPRM on flammability relating to commercial fleet retrofit. In public hearings in 1977, the withdrawal of these initiatives was recommended because of their piecemeal approach and the lack of adequate full-scale supporting data. The former criticism led to an attempt to develop a combined hazard index (reference 1). The formation of an advisory committee was recommended as well at the 1977 hearings, and this led to the establishment of the Special Aviation Fire and Explosion Reduction (SAFER) committee whose findings were published in 1980 (reference 2). Although the SAFER committee made numerous recommendations relating to both fuel fire hazards and aircraft material flammability, smoke, and toxicity; three specific recommendations are noteworthy with regard to the direction they gave to subsequent FAA research and development. The SAFER committee recommended the specific fire scenario for the FAA to use in full-scale C133 tests. The committee recommended expedited development and evaluation of the Ohio State University (OSU) Rate of Heat Release Apparatus as the potential standardized test for materials. Additionally, the committee recommended for technology development purposes that a 5-minute evacuation time be considered to represent the majority of cases (reference 2). In response to these and other recommendations of the SAFER committee, the FAA developed a formal program plan (reference 3) that would guide its research to achieve the goals set by the SAFER committee. The initial major step involved the implementation of the broad committee full-scale test goals into an actual operational test article with a workable and repeatable test method. This early work resulted in characterization of the full-scale fire environment as well as identification of flashover as the dominant event marking the end of survivable conditions in the cabin (reference 4). Further work involving the full-scale evaluation of seat blocking layers (references 5 and 6) continued to show flashover of the cabin interior as the time at which survivable conditions ended. In fact, the benefits in survivability attached to seat blocking layers have been quantitatively tied to the time to flashover (reference 7). The importance of flashover in the

SAFER recommended scenario cannot be overstated, as these full-scale test results provided a technical basis for the FAA to concentrate on material flammability as the driving factor in cabin survivability. For the most part, the tests showed that smoke and toxic gases became a survivability threat only when enough cabin materials were burning to cause flashover conditions.

The seat-blocking layers delayed flashover by slowing down the heat release rate of burning seat materials. This was accomplised by delaying ignition of the seats and by shielding the urethane foam from nearby fire sources. To determine potential flashover delays available from improved cabin lining materials, full-scale comparative tests were performed with epoxy type panels and advanced fireproof panels provided by National Aeronautics and Space Administration (NASA) (reference 8). These tests showed a 140-second flashover delay when the severe rupture scenario was employed (wherein a seat row is directly exposed to an external fuel fire) and prevention of flashover when the cabin was exposed to a fuel fire through an open fuselage doorway. This finding was significant because it showed that further improvements in survivability were possible through lessened panel flammability.

The approach to this effort on panels involved subjecting prototype panels of various constitution (epoxy, phenolic, fiberglass, graphite, kevlar™, etc.) to a battery of standard laboratory scale fire tests and to one-quarter scale flashover tests in a controlled enclosure. Correlation of the results led to a preliminary recommendation that the OSU device be targeted as the most promising test method for determining panel flammability (reference 9). The culmination of the effort on flammability of the interior panels was a series of full-scale fire tests on the prototype panels along with extensive OSU tests involving various operational modes and many additional materials.

OBJECTIVES.

This work had two primary objectives. The first was the determination through full-scale fuselage fire tests, whether the OSU Rate of Heat Release Apparatus was an acceptable indicator of the fire performance of interior panels. The second objective was the determination of the relationship between panel fire performance and enhanced survivability in a specific postcrash fire scenario.

TEST MATERIALS

Although many different panel materials have been evaluated as part of the overall test effort, five panels were used most extensively in the development of the correlation between full-scale and small-scale tests. These were honeycomb panels constructed for the Federal Aviation Administration (FAA) by General Veneer Manufacturing Company in South Gate, California. The physical overall description of each panel is given in table 1. All the test panels had a phenolic-dipped Nomex™ core and a 2-mil Tedlar™ decorative surface on one exterior surface. The facesheets that actually sandwiched the core were the only constituent of the panel assembly that varied among the five panels. The facesheets are composed of a fabric impregnated with a resin. The fabrics tested included fiberglass, kevlar, and graphite while the resins included epoxy and phenolic. These various components are representative of the components used in state-of-the-art aircraft interiors. The epoxy facesheets (panel 1 and 3) were purchased as prepregnated sheets by General Veneer. The epoxy/glass was procured from Ciba-Geigyic. and the epoxy/kevlar from Fiberite. General Veneer assembled the constituent parts of

TABLE 1. DESCRIPTION OF TEST PANELS

No.	Designation	Description
1	EP/FG	Epoxy glass facings, face and back 1-ply 7781 fiberglass impregnated with resin, fire retardant, and co-cured 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.36 lbs/sq. ft.
2	PH/FG	Phenolic glass facings, face and back 1-ply 7781 style woven fiberglass impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.42 lbs/sq. ft.
3	EP/KE	Epoxy Kevlar tm facings, face and back 1-ply 285 style woven Kevlar impregnated with epoxy resin, fire retardant, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.38 lbs per sq. ft.
4	PH/KE	Phenolic Kevlar facings, face and back 1-ply 285 style woven Kevlar impregnated with a modified phenolic resin and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.38 lbs per sq. ft.
5	PH/GR	Phenolic graphite facings, 1-ply 8 harness satin, 3K fiber T-300 woven graphite impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.36 lbs/sq. ft.

Note: Weight is based on nominal weight of the components.

the epoxy facesheets into panels by curing them at 265° F for 1 hour. The phenolic facesheets employed a benzyl phenolic from Weyerhauser. The fabrics in this case were not bought by General Veneer as prepregs. The cure time for the phenolic panels was approximately 2 hours. The panel assemblies were heated in a press to 275° F. The press was opened to relieve any solvent gases. The panel was then raised under pressure to 320° F where it was cured for one hour. These times and temperatures may be slightly higher than those used by the airframe manufacturers, but they are certainly comparable. This is in contrast to the advanced polyimide panel used to find the upper limit to delay of flashover. That panel consisted of a polyimide dipped nomex core, an American Cyanamid polyimide resin on the fiberglass facesheets, and a polyetheretherketone (peek) decorative surface. Assembly of this panel involved a 16-hour cure at 500° F.

Performance of these panels under various fire test methods has been previously documented (references 9 and 10). Procurement of these panels provided a range of performance adequate for correlation purposes and ensured test specimen uniformity in the testing done at various laboratories. Among the laboratories participating in the early part of this effort were the FAA Technical Center, the National Bureau of Standards, the Jet Propulsion Laboratory, and Factory Mutual Research Corporation (references 9, 10, and 11).

FULL-SCALE FIRE TESTS

TEST CONFIGURATIONS.

The C-133 test fuselage was configured in these tests with an open doorway exposed to an external fuel fire as previously done for seat blocking layers and advanced panel work (references 5, 6, and 8). Figure 1 shows a schematic of the fuselage. The panels described earlier were tested in two modes — the panels alone and panels with a complement of seats and carpeting. Additionally, the peek/polyimide panels tested previously (reference 8) were included in these tests for comparative purposes. The panels were tested alone as well as in conjunction with other materials to ensure that findings on cabin hazards were due to changes in panel performance rather than interactions with other furnishings. Figure 2 shows the configurations used for panels alone. The interior surfaces around the C-133 doorway had panels configured as sidewalls, ceiling, overhead stowage bins, and a simulated galley wall. The tests involving other materials were configured as shown in figure 3 and involved four sets of double seats with Norfab blocking layers and wool/nylon aircraft carpet in the vicinity of the doorway.

The tests of panels without seats and carpet showed the propensity of the various panels to be ignited and release heat. There was not enough fuel load in the fuselage to attain flashover type conditions throughout the fuselage. Thus, in these tests the fuselage interior temperature rise represents the most significant quantitative data. In tests with panels, seats, and carpets, the fuel load is more realistic and large enough to create the kind of flashover conditions found previously for this type scenario (references 6 and 8). Thus, in addition to the temperature versus time data, the time to flashover is significant. With flashover as the survivability endpoint, the time of escape can be estimated from this information.

The tests described here are considered representative tests. Other panels and other scenarios were tested and some repeat tests were performed. For instance, a series of in-flight fire scenarios were performed with the test panels. However, the main purpose was to evaluate the relation of full-scale fire performance of honeycomb panels to their performance in the OSU device within the context of a post-crash fire scenario.

PANELS WITHOUT SEATS.

The type panel performance under exposure to a pool fire outside a doorway can be represented by photographic documentation. Figure 4 shows an interior view at 5 minutes into the test with peek/polyimide as the test specimen. At no time did these panels evidence any fire involvement. An intermediate case is represented by the phenolic/graphite panel (No. 5) in figure 5 which shows the decorative Tedlar burning off at 1 minute into the test but with the panels relatively uninvolved at 1 minute and 40 seconds. A poor performance by the phenolic/kevlar panel (No. 4) is shown in figure 6. At 1 minute, the decorative Tedlar is burning off, but at 1 minute and 55 seconds, the panel facesheet is undergoing sustained burning.

Figure 7 shows temperature versus time curves for the panels. The least temperature rise is associated with the peek/polyimide which demonstrated no apparent fire involvement. The most significant temperature increases are associated with epoxy/fiberglass (No. 1) and phenolic/kevlar (No. 4), although the temperature curve for epoxy/kevlar (No. 3) eventually surpasses the epoxy/fiberglass. Intermediate temperature rises are shown by phenolic/fiberglass (No. 2) and phenolic/graphite (No. 5), although early in the test phenolic/fiberglass results in substantially lower temperature rise than phenolic/graphite.

Figure 8 shows a comparison of smoke production in the C-133 during these tests. Epoxy/fiberglass, phenolic/kevlar, and epoxy/kevlar all show significant smoke production during the test. The phenolic/fiberglass and the phenolic/graphite along with peek/polyimide show negligible smoke production.

Figure 9 shows comparative data for the measurement of carbon monoxide in these tests. These data are similar to the smoke production data in that phenolic/fiberglass and phenolic/graphite perform near the peek/polyimide while the epoxy/fiberglass, the phenolic/kevlar, and the epoxy/kevlar are noticeably higher. Comparative data on hydrogen fluoride is shown in figure 10. Except for the phenolic/kevlar which showed unexpectedly high readings, the levels provided by the panels are comparable and are traceable to the Tedlar surfaces which were the same for all the panels except peek/polyimide.

The overall fire performance of the panels in this test series was similar to that found in the small-scale enclosure tests used for preliminary correlation work (reference 9). These tests demonstrated that the earlier 1/4-scale model work was an adequate surrogate for the full-scale testing of panels by themselves. Subsequent full-scale tests with seats and carpets were needed to determine if the relative panel performance remained the same under a more representative interior configuration.

PANELS WITH SEATS.

With the addition of seats and carpet, enough fireload was located near the fuselage doorway so that flashover could occur. Figure 11 shows combined temperature, smoke, and gas data taken during the test with phenolic/kevlar panels. As found in previous studies of similar scenarios (references 4 and 8), at the time of flashover there is a sudden deterioration of the cabin environment from thermal, smoke, and toxicity parameters.

As with the fire tests of panels themselves, the photographic documentation provides a clear picture of the relative performance of the materials. Figure 12 shows the degree of fire involvement for five different panels at 1 minute and 30 seconds into the test. For interiors made of either phenolic/fiberglass or peek/polyimide, the cabin environment is still stable as the fire has not spread into the interior. For the phenolic/graphite interior, the fire in the cabin is in a growth stage with localized burning of the seats and carpet near the doorway. The worst situation is evidenced by the epoxy/fiberglass and phenolic/kevlar linings where the furnishings and linings near the door are totally involved in fire. These photographs are particularly significant with regard to the phenolic/graphite panels. When previously tested without seats, this panel demonstrated early, but unsustained flammability, which resulted in its performance appearing similar to phenolic/fiberglass. However, when configured with seats and carpet, this early flammability can sustain itself through interaction with the seats and carpet.

Figure 13 shows the cabin interior for three materials at 3 minutes and 40 seconds into the test. With peek/polyimide interior, there is still no fire involvement of the cabin materials. For the phenolic/graphite panels, the cabin is completely enveloped in flames. For the phenolic/fiberglass, the fire is in a growth stage with burning seat backs and panels in evidence.

Figures 14 through 18 show the temperature profiles at 1-foot vertical intervals at station 270 in the fuselage for the tests with panels and seats. The profile at the ceiling for each panel tested is shown in figure 19. The epoxy/fiberglass and phenolic/kevlar interiors show an early temperature growth reflective of early flashover. The phenolic/graphite shows a relatively early rise to moderate temperatures (approximately 570° F) where the temperature remains until flashover is indicated, approximately 2 minutes later. Phenolic/fiberglass performs like the peek/polyimide until flashover develops approximately 4 minutes into the test. There was no flashover with the peek/polyimide panels.

The smoke profiles in figure 20 are consistent with the comparative temperature profiles. The hydrogen fluoride profiles in figure 21 are further reflective of the phenomena occuring in the C-133. The epoxy/fiberglass and the phenolic/kevlar, which reached flashover early, evidence an early release of hydrogen fluoride. The phenolic/graphite panel, which showed early fire involvement, shows an early peak in hydrogen fluoride with a later smaller peak when the interior reaches flashover.

The phenolic/fiberglass panel has virtually no hydrogen fluoride for the first several minutes, and this is consistent with the lack of interior fire growth over the first 3 minutes. The phenolic/fiberglass test shows a peak in hydrogen/fluoride when fire growth near the doorway occurs. This peak is at the same time as the corresponding photograph in figure 13.

The times to flashover in these tests are shown in figure 22. Flashover was determined from photographic coverage and time temperature profiles. The peek/polyimide interior did not reach flashover at all. The phenolic/graphite reached flashover a little earlier than the phenolic/fiberglass, although the phenolic/graphite interior had sustained fire growth into the interior approximately 2 minutes prior to flashover. Both epoxy/fiberglass and phenolic/kevlar reach flashover conditions a little more than a minute into their respective tests.

CRITERIA DEVELOPMENT

The notice of proposed rulemaking on interior materials issued on April 16, 1985 (appendix A), was based on preliminary evaluation of a variety of test methods in conjunction with panel performance in small-scale enclosure fires (reference 9). Fine tuning the test methodology involved further correlation of OSU results with the full-scale test results reported here, along with a government-industry round-robin testing effort to establish improved laboratory repeatability with the OSU device. These efforts resulted in recommended changes to the OSU methodology (appendix B).

Table 2 shows the performance of the test panels as tested by the OSU methodology described in appendix B. These data were taken from the OSU apparatus at the FAA Technical Center. More detailed documentation of the development of this methodology is in progress (references 12 and 13). One salient result from this methodology development was the finding that heat release determined from thermopile correlated against heat release found from oxygen depletion with a high degree of confidence for a range of materials. Thus, the data in table 2 are all derived from thermopile measurements with a sample exposure of 3.5 watts per centimeter squared.

TABLE 2. OSU DATA FOR PANELS USED IN THE C-133

Panel Type	Peak* (KW/M2)	2-Min. Total*(KW-Min/M2)
EP/FG	92.6	82.4
PH/FG	58.3	53.4
EP/KV	76.8	86.1
PH/KV	84.4	92.8
PH/GR	69.4	78.7
PEEK/PI	7.5	3.4

*AVERAGE OF 3 TESTS

Selection of pass-fail criteria for materials can be based on evaluation of the full-scale test data. Phenolic/kevlar shows a peak heat release rate of 84 and a 2-minute integrated heat release of 93 in the OSU device. This material sustained an early flashover in the C-133 tests. This indicates that criteria definitely should be set below these numbers. Epoxy/fiberglass shows OSU data of 93 for peak and 82 for 2-minute integrated heat release. Phenolic/graphite shows a peak of 69 and a 79 total for 2 minutes. Concentrating on the 2-minute total, the epoxy/fiberglass and the phenolic/graphite are indistinguishable. Nevertheless, the flashover for phenolic/graphite occurred nearly 2 minutes after the flashover for epoxy/fiberglass which occurred very early. This indicates that the overall region between 69 and 93 for peak heat release and in the vicinity of 80 for 2-minute integrated heat represents an area of transition from high flammability to low flammability for the materials in the full-scale scenario used. This transition means that materials may or may not contribute to early flashover, depending on the chain of events within the cabin, once materials get involved. This can be shown in figures 19 and 21 if the phenolic/graphite graphs are evaluated. The phenolic/graphite demonstrates an early release of hydrogen fluoride and an early temperature rise at about 80 seconds into the test. Whether this early release of heat leads to a flashover quickly is somewhat probabilistic. The epoxy/fiberglass curve also shows involvement through the evolution of hydrogen fluoride from the Tedlar surface. In this case flashover occurs quickly.

Setting criteria near the OSU numbers evidenced by phenolic/graphite and epoxy/fiberglass would certainly not assure improved safety. In fact, the full-scale testing did not include the many small thermoplastic parts associated with an aircraft interior as well as various carry-on type items. With the added flammability of these items, flashover early would be likely with materials of the heat release potential of epoxy/fiberglass and phenolic/graphite.

The best material shown in these tests was peek/polyimide which showed a peak of 8 and a 2-minute integrated value of 3 in the OSU. With this material, there was no flashover in the C-133. Quite definitely this represents a safety improvement.

Figures 19 and 21 indicate that the phenolic/fiberglass behaves similar to the peek/polyimide right up to the time of flashover at 4 minutes. There is no early heat release and no early development of hydrogen fluoride indicative of a burning Tedlar surface. The OSU peak and total values for phenolic/fiberglass are 58 and 53, respectively. These values seem to assure some measure of improved safety. The rationale for setting limits at 65 kw/m^2 for the peak and 65 kw-min/m^2 for the 2-minute OSU total is to encompass this phenolic/fiberglass material and to stay below the transition region demonstrated by the epoxy/fiberglass and the phenolic/graphite. Further testing would be needed to determine if these recommended limits should be lowered to 60 to more tightly bracket the phenolic/fiberglass performance.

Figure 23 shows comparative fractional effective doses for the materials from the C-133 tests. These allow survivability type estimates to be done in a quantitative manner as with the seat blocking layers (reference 5). Taking 2 minutes as the time to flashover for existing in-service panels (e.g., epoxy/fiberglass) from previous work, movement to an interior of phenolic/fiberglass panels like the one tested in the C-133 would appear to add approximately 2 minutes to survivability.

SUMMARY DISCUSSION

Although a number of different type laboratory-scale fire tests were evaluated in this program, the successful correlation of full-scale fire tests and rate of heat release test devices can be explained. The specific full-scale fire scenarios employed by the FAA have been useful in finding the time to flashover with a wide variety of interior furnishings. The rationale for employing fire blocking layers on aircraft seats was the additional escape time available due to delayed onset of flashover. Nevertheless, flashover is an enclosure phenomenon that generally occurs when a fire within the enclosure generates heat at some critical rate that is affected by heat transfer and ventilation effects. Flashover is to a large degree caused by the heat release rate of burning materials within the fuselage.

In an analysis of the contributing factors to flashover in the C-133 (reference 10), the flashover event corresponded to a heat release rate of approximately 1000 kilowatts by burning carpet, seats, and wall lining materials. The role of the external pool fire in these tests is primarily to radiatively heat the interior materials to a temperature where they can sustain flame spread. The flashover itself results from the combined rate of heat release from these burning materials. Thus, a rate of heat release test device, that can irradiate materials by flux levels similar to those found in the full-scale test article, by its very design will yield the contributory potential of a given material to the flashover event. The correlation results cited in this report (reference 12 and 13) are most important in the development of the test device heat flux that best reflects the array of heat fluxes that exist in the full-scale test article at various distances from and angles to the fuel fire covered doorway.

Probably any of the heat release rate tests used in this program could be adequately correlated with full-scale tests so that they could be used to establish the flashover yielding potential of various materials. The decision to select the OSU device was based on recommendations of the SAFER committee, the use of the OSU in the development of the Combined Hazard Index, the availability of the device in the aircraft industry, and the fact that the OSU is an ASTM designated test.

The actual criteria for material selection are driven by the level of fire safety desired as evidenced in full-scale testing. Clearly, the ultimate in fire safety would be lining materials that were virtually non-combustible. The effectiveness of such an approach is documented with full-scale testing of peek/polyimide panels (reference 8) which showed a flashover delay in excess of 2 minutes in the fuselage rupture scenario. Nevertheless, these advanced panels are beyond the state-of-the-art in processing and totally unsuitable for use in an aircraft. This performance really demonstrates the ultimate benefit attainable, much as non-combustible seat cushions were used as a yardstick in the seat fire blocking layer test program (reference 5). Another option would be to set test criteria at the performance level of epoxy-type in-service panels which were tested along with the peek/polyimide panels for comparison. However, such a performance level would lead to no new safety benefit on newly manufactured aircraft. The one material that tested well under virtually any test condition was the phenolic/fiberglass panel designated as panel No. 2. The performance of this panel was similar to the best in-use panels in the OSU device. Thus, the improved survivability documented in full-scale tests of panel No. 2 are achievable with state-of-the-art manufacturing processes. Thus, panel No. 2 was used as a benchmark to select the recommended performance criteria for OSU testing of aircraft materials. Both the peak OSU heat release and the 2-minute total heat release, when established at 65 kw/m^2 and 65 $kw\text{-}min/m^2$, respectively, encompass this material. Besides the good performance of this panel in the full-scale tests, the full-scale tests indicate that an increase in OSU 2-minute heat release of approximately 30 percent (panel No. 1 versus panel No. 2) results in dramatic erosion of fire safety. The full-scale tests demonstrate that the flammability performance of the interior is very sensitive to relatively small changes in material heat release potential.

CONCLUSIONS

1. Aircraft interior panels with low heat release rate characteristics improve survivability for certain types of postcrash cabin fire scenarios.

2. OSU apparatus heat release rate measurements on aircraft interior panels correlate with full-scale cabin fire test results.

3. OSU apparatus acceptance criteria for aircraft interior panels based on the performance of a phenolic/fiberglass panel evaluated during this study will improve survivability for certain types of postcrash cabin fire scenarios.

4. The increase in cabin air temperature from heat released by aircraft interior panels during full-scale fire tests tracked the smoke and toxic gas concentrations.

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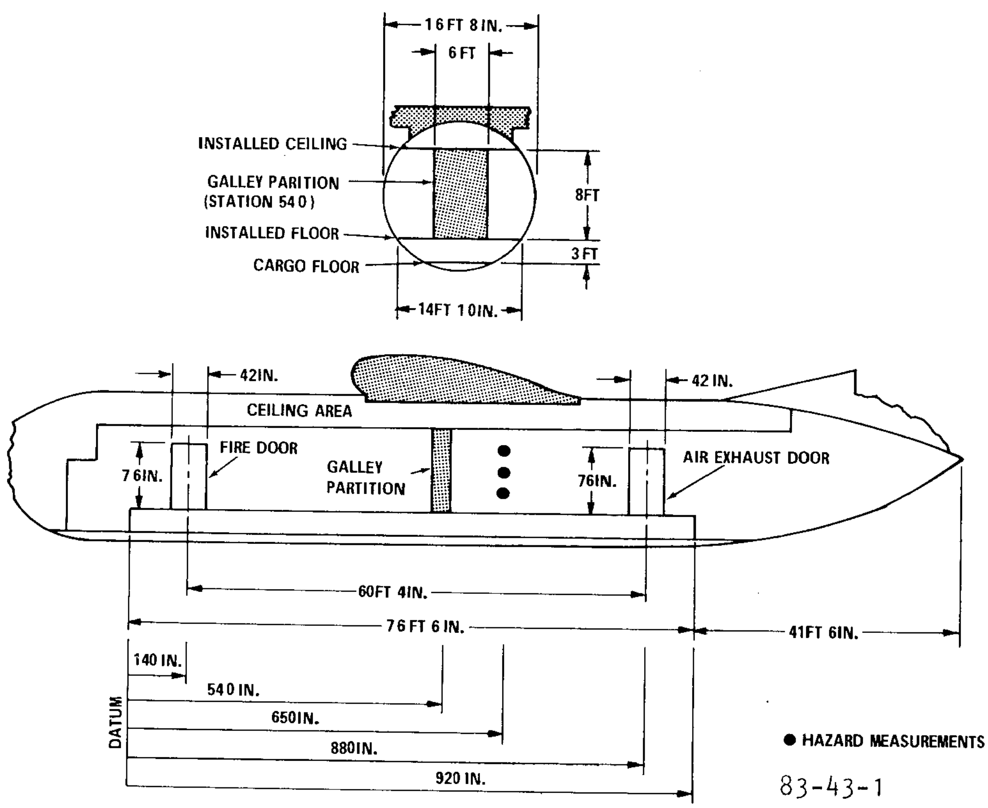

FIGURE 1. SCHEMATIC OF C-133